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(54) **AC LED LAMPS AND CONTROL METHODS THEREOF**

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H05B 33/08 (2006.01)

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CPC **H05B 33/083** (2013.01); **H05B 33/0815**
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USPC 315/185 R, 186, 192, 193, 200 R, 201,
315/205, 209 R, 210, 224, 226, 291, 294,
315/297, 299, 307, 311, 313, 312, 362
See application file for complete search history.

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(57) **ABSTRACT**

A LED lamp has LED groups, a path controller, a power bank, and a bank controller. The LED groups are arranged in series between a rectified input voltage and a ground voltage. The path controller controls path switches, each path switch for coupling a corresponding LED group to the ground voltage. The power bank is coupled between the rectified input voltage and the ground voltage, having a capacitor and a discharge switch. The capacitor is configured to be charged when the rectified input voltage exceeds a capacitor voltage of the capacitor. The discharge switch is connected between the capacitor and the rectified input voltage. The bank controller determines a connection period and controls the discharge switch in response to a signal turning ON one of path switches, in order to make the capacitor capable of being discharged to the rectified input voltage during the connection period.

17 Claims, 6 Drawing Sheets

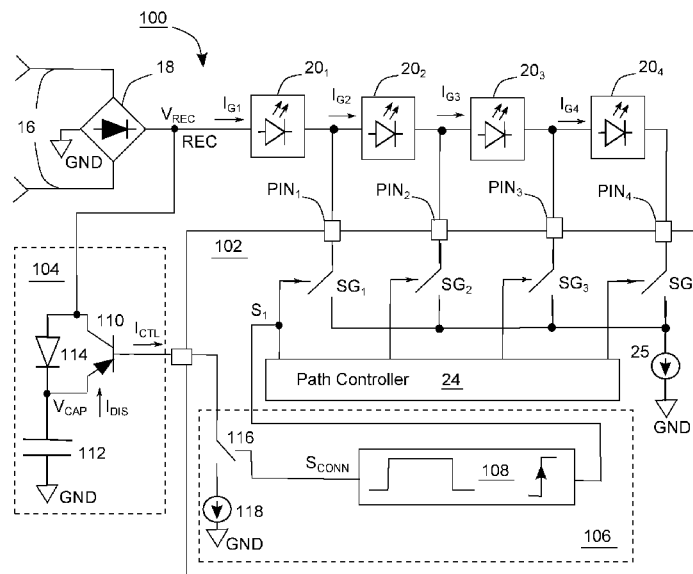


FIG. 2 (PRIOR ART)

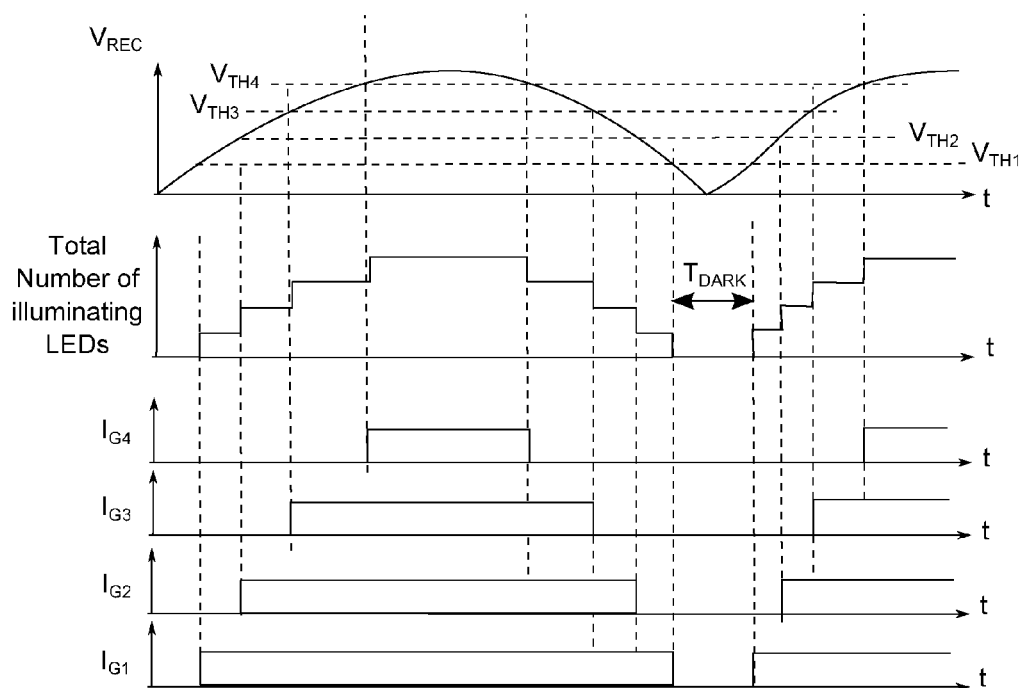
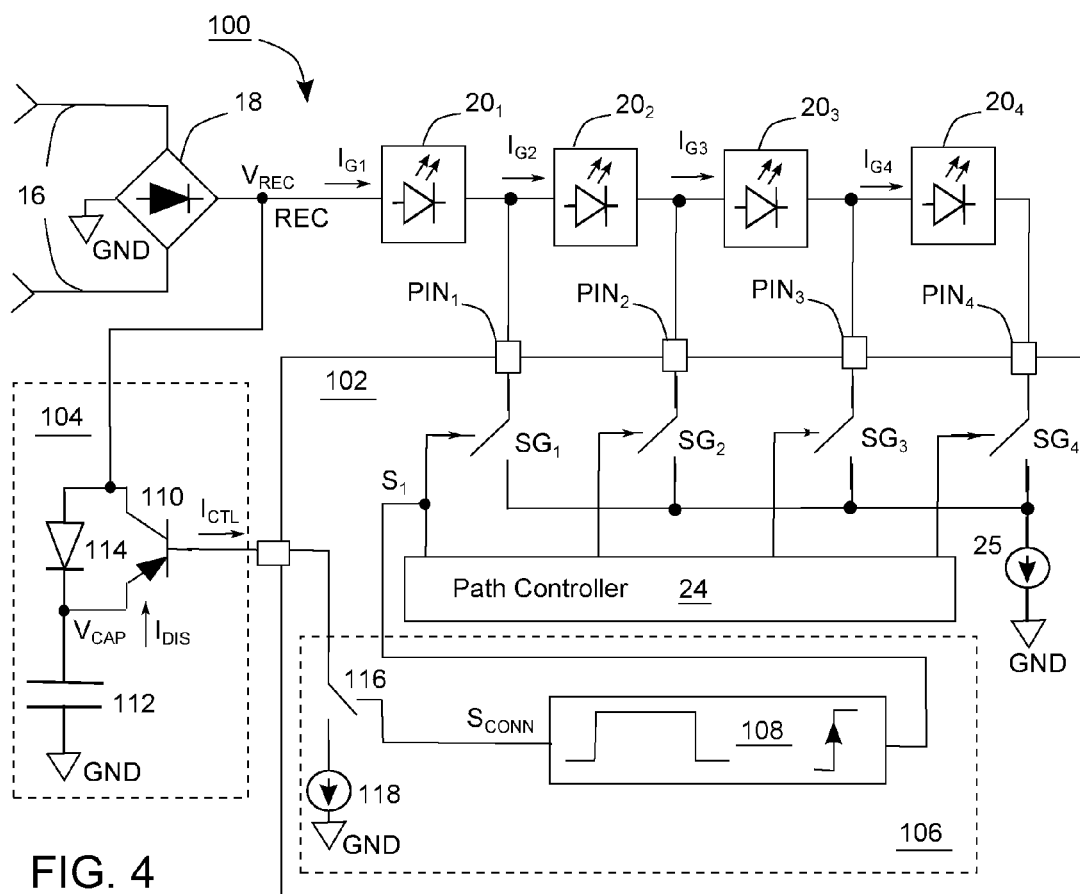


FIG. 3 (PRIOR ART)



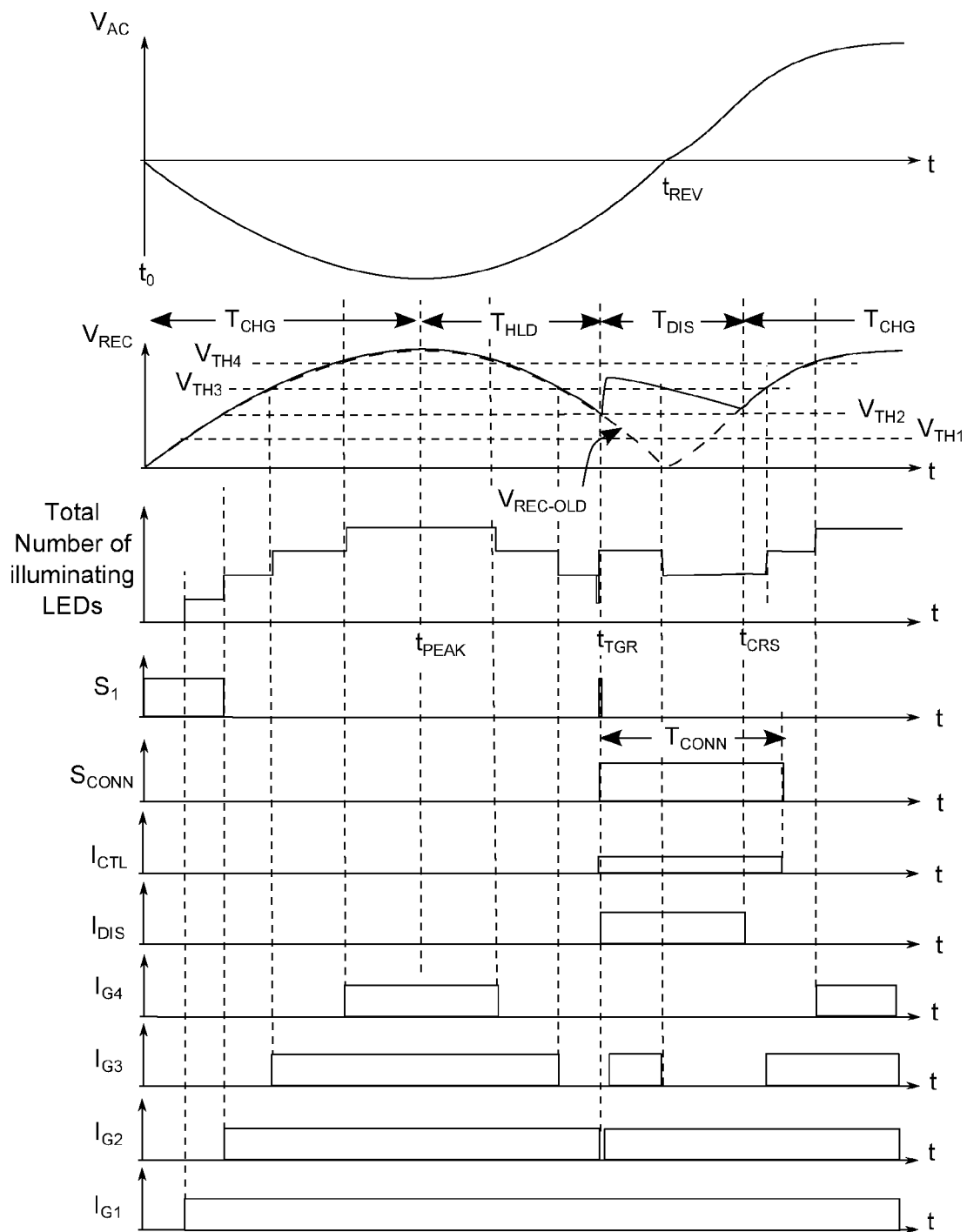


FIG. 5

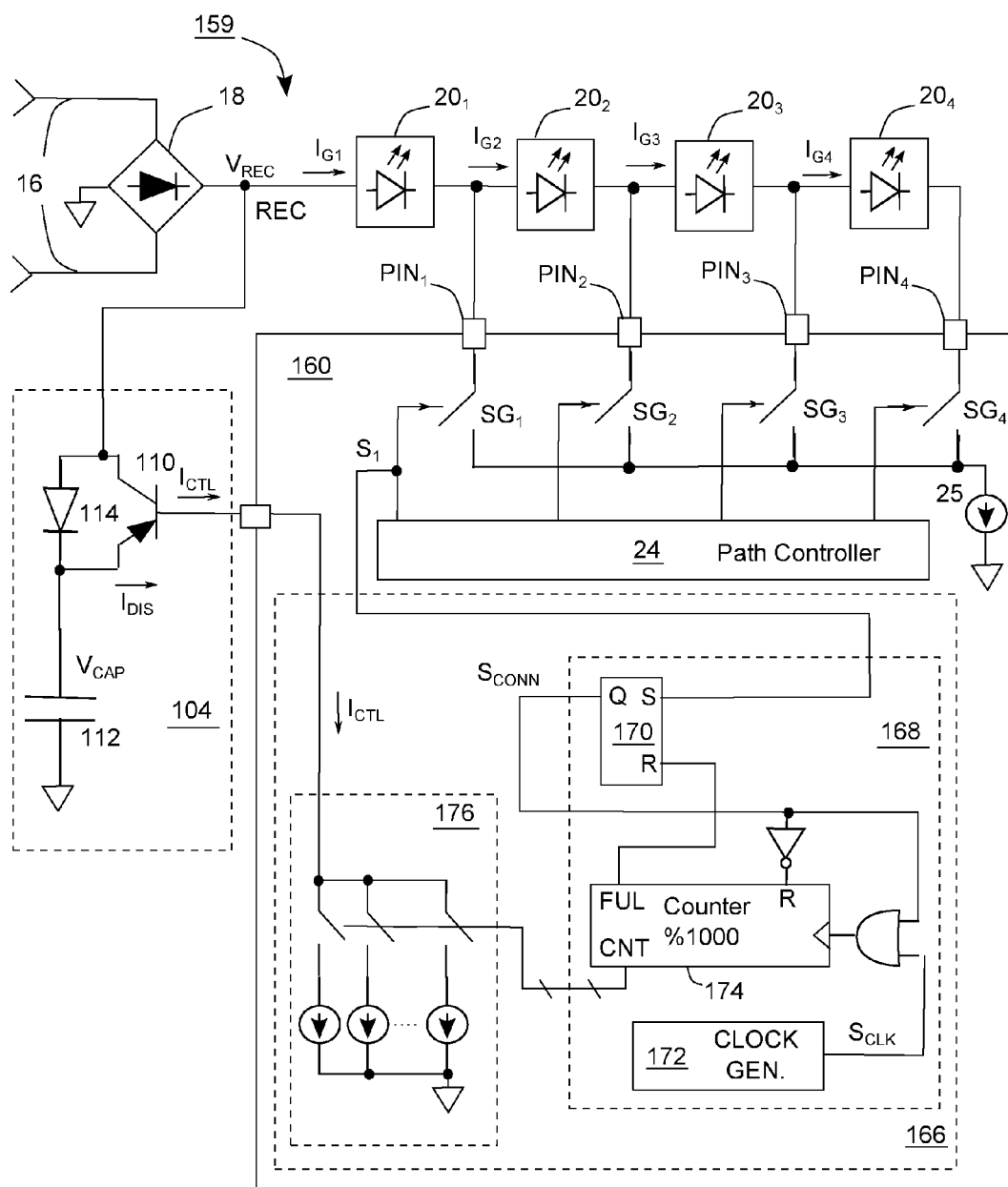


FIG. 6

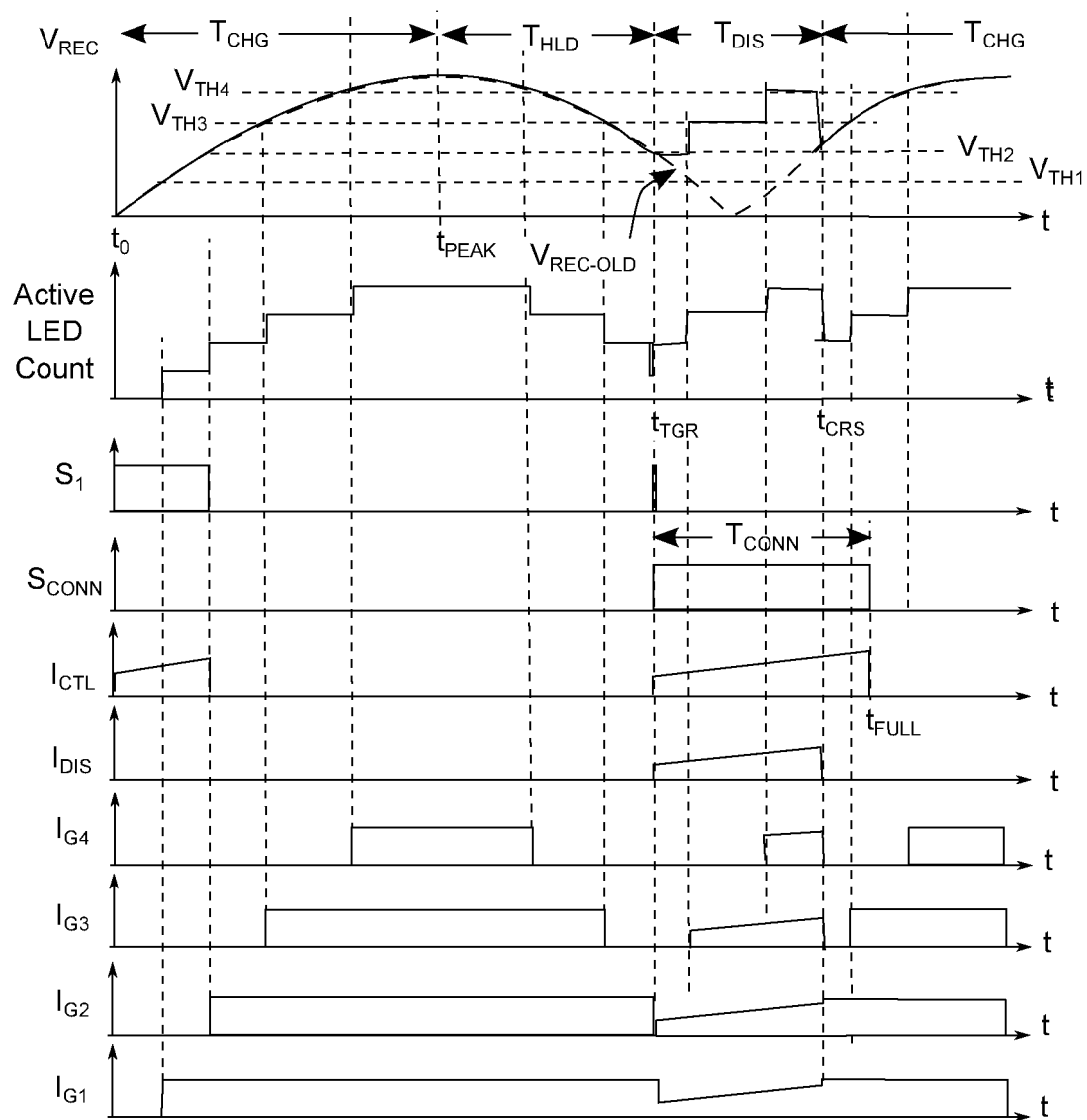


FIG. 7

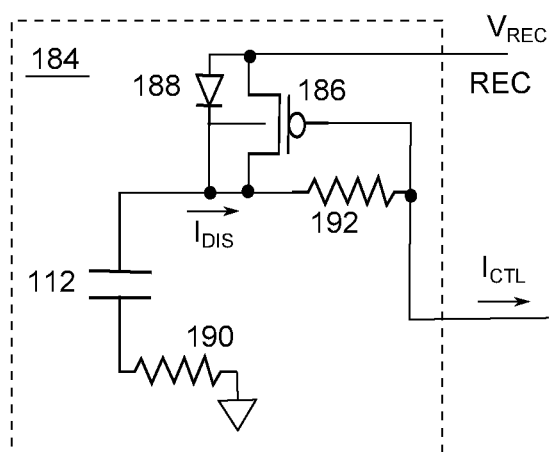


FIG. 8

AC LED LAMPS AND CONTROL METHODS THEREOF

BACKGROUND

The present disclosure relates generally to Light-Emitting Diode (LED) lamps, and more particularly to Alternating Current (AC) driven LED lamps and control methods thereof.

Light-Emitting Diodes or LEDs are increasingly being used for general lighting purposes. In one example, a set of LEDs is powered from an AC power source and the term "AC LED" is sometimes used to refer to such circuit. Concerns for AC LED include manufacture cost, power efficiency, power factor, flicker, lifespan, etc.

FIG. 1 demonstrates AC LED lamp 10 in the art, which, in view of electric circuit, simply has a LED module 12 and a current-limiting resistor 14. The LED module 12 consists of two LED strings connected in anti-parallel. The AC LED circuit 10 in FIG. 1 requires neither an AC-DC converter nor a rectifier. Even though a DC voltage is also compatible, an AC voltage is typically supplied to input port 8 and directly powers the AC LED circuit 10. Simplicity in structure and low-price in manufacture are two advantages the AC LED circuit 10 provides. Nevertheless, the AC LED circuit 10 can only emit light in a very narrow time period in each AC cycle time, suffering either low average luminance or high-current stress to LEDs.

FIG. 2 demonstrates another AC LED lamp 15 in the art. Examples of the AC LED lamp 15 can be found from U.S. Pat. No. 7,708,172. The AC LED lamp 15 employs full-wave rectifier 18. A DC or AC voltage source is received on input port 16. A string of LEDs are grouped into LED groups 20₁, 20₂, 20₃, and 20₄. An integrated circuit 22 has nodes PIN₁, PIN₂, PIN₃, and PIN₄, connected to the cathodes of LED groups 20₁, 20₂, 20₃, and 20₄ respectively. Inside integrated circuit 22 are path switches SG₁, SG₂, SG₃, and SG₄, and a path controller 24 as well. When the voltage on input port 16 increases, controller 24 can switch path switches SG₁, SG₂, SG₃, and SG₄, to possibly make more LEDs emit light. Operations of integrated circuit 22 have been exemplified in U.S. Pat. No. 7,708,172 and are omitted here for brevity.

FIG. 3 illustrates the waveforms of signals when the input port 16 in FIG. 2 is supplied with an AC sinusoidal input voltage. The upmost waveform shows a rectified input voltage V_{REC} , which, as indicated in FIG. 2, refers to the voltage the full-wave rectifier 18 provides to LED group 20₁. The second waveform shows the total number of illuminating LEDs, meaning the number of LEDs that are illuminating. The four following waveforms regard with currents I_{G4} , I_{G3} , I_{G2} and I_{G1} , which as shown in FIG. 2, refer to the currents flowing through LED groups 20₄, 20₃, 20₂ and 20₁, respectively. The total number of illuminating LEDs rises or descends stepwise, following the increase or decrease of the rectified input voltage V_{REC} . When the rectified input voltage V_{REC} increases, LED groups 20₁, 20₂, 20₃, and 20₄, according to a forward sequence, join to illuminate. For example, when the rectified input voltage V_{REC} increases to just exceed the threshold voltage V_{TH1} , the voltage required for driving the LED group 20₁ to illuminate, the LED group 20₁ starts illuminating. When the rectified voltage V_{REC} decreases, LED groups 20₁, 20₂, 20₃, and 20₄ darken according to a backward sequence. If, for example, the rectified input voltage V_{REC} just falls below the threshold voltage V_{TH4} , the voltage required for driving all the LED groups 20₁, 20₂, 20₃ and 20₄ to illuminate, then the path switch SG₃ is switched ON, such that the LED group 20₄ stops illuminating, leaving only the LED groups 20₁, 20₂ and 20₃ to emit light. The AC

LED lamp 15 enjoys simple circuit architecture and, as can be derived, good power efficiency.

There in FIG. 3 however has a dark period T_{DARK} when no LED illuminate, because the rectified voltage V_{REC} is too low to drive the LED group 20₁. If the rectified voltage V_{REC} is a 120-Hertz signal, the voltage valley, where the rectified voltage V_{REC} is about zero Volt, appears at 120 Hz, causing the dark period T_{DARK} to show up in the same frequency of 120 Hz. Even though the dark period T_{DARK} at 120 Hertz might not be perceivable by human eyes, reports indicate that when a digital camera takes a photograph of an object exposed under the luminance of the LED lamp 15, the photograph comes out with unwelcome dark lines due to the existence of the dark period T_{DARK} . It is appreciated for an LED lamp to introduce no dark period T_{DARK} .

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be more fully understood by the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

FIG. 1 demonstrates an AC LED lamp in the art;

FIG. 2 demonstrates another AC LED lamp in the art;

FIG. 3 illustrates the waveforms of signals when the input port in FIG. 2 is supplied with an AC sinusoidal input voltage;

FIG. 4 demonstrates an AC LED lamp according to embodiments of the invention;

FIG. 5 demonstrates some waveforms of signals in FIG. 4;

FIG. 6 demonstrates another AC LED lamp according to embodiments of the invention;

FIG. 7 demonstrates some waveforms of signals in FIG. 6; and

FIG. 8 demonstrates another power bank.

DETAILED DESCRIPTION

The following embodiments are described in sufficient detail to enable those skilled in the art to make and use the invention. It is to be understood that other embodiments would be evident based on the present disclosure, and that improves or mechanical changes may be made without departing from the scope of the present invention.

In the following description, numerous specific details are given to provide a thorough understanding of the invention. However, it will be apparent that the invention may be practiced without these specific details. In order to avoid obscuring the present invention, some well-known configurations and process steps are not disclosed in detail.

FIG. 4 demonstrates an AC LED lamp 100 according to embodiments of the invention. The AC LED lamp 100 has a full-wave rectifier 18 to rectify a sinusoid input voltage V_{AC} at an input port 16, and provides a rectified input voltage V_{REC} at node REC and a ground voltage at GND node. The LED groups 20₁, 20₂, 20₃ and 20₄ form a LED string and are connected in series between the rectified input voltage V_{REC} and the ground voltage. Each LED group might consist of several LEDs connected in parallel or in series, depending on its application. The LED group 20₁ is the most upstream LED group in FIG. 4 as its anode is connected to the highest voltage in the LED string, the rectified input voltage V_{REC} . Analogously, the LED group 20₄ is the most downstream LED group in FIG. 4.

An integrated circuit 102 has path switches SG₁, SG₂, SG₃ and SG₄, a path controller 24, and a bank controller 106. Each of path switches SG₁, SG₂, SG₃ and SG₄ connects one cathode of an LED group to a current source 25, which limits the maximum driving current from the LED string to the ground

3

voltage. For example, the path switch SG_1 controls the connection between the cathode of the LED group 20_1 and the current source **25**. The path controller **24** is configured to control the path switches SG_1 , SG_2 , SG_3 and SG_4 . For example, if the rectified input voltage V_{REC} is so low that the current I_{G4} passing through the LED group 20_4 is about 0 A, then the path controller **24** turns on the path switch SG_3 , coupling the cathode of the LED group 20_3 directly to the current source **25**.

The AC LED lamp **100** includes a power bank **104** coupled between the rectified input voltage V_{REC} and the ground voltage. The power bank stores electric energy when the absolute value of the sinusoid input voltage V_{AC} is relatively high, and releases its stored energy to the LED string when the absolute value of the sinusoid input voltage V_{AC} is relatively low. The power bank **104** has a diode **114** connected between the node REC and the capacitor **112**. As a result, when the rectified input voltage V_{REC} exceeds the capacitor voltage V_{CAP} of the capacitor **112**, a current conducted through the diode **114** charges the capacitor **112**, and the capacitor voltage V_{CAP} increases. A PNP BJT **110** acts as a discharge switch, connected between the rectified input voltage V_{REC} and the capacitor **112**. When there is a non-zero control current I_{CTL} draining from the base of the BJT **110**, and the capacitor voltage V_{CAP} is higher than the rectified input voltage V_{REC} , then the BJT can conduct a charge current I_{DIS} from the capacitor **112** to the node REC, powering the LED string. In other words, the BJT **110** can be turned ON by the control current I_{CTL} , and then the energy stored in the capacitor **112** could be released to illuminate one of the LED groups 20_1 , 20_2 , 20_3 and 20_4 . As to when the control current I_{CTL} starts and how much the control current I_{CTL} is, it is up to the control of the bank controller **106** inside the integrated circuit **102**.

In FIG. 4, the bank controller **106** has a pulse generator **108**, a switch **116** and a constant current source **118**. The pulse generator **108** is configured to response to signal S_1 , which the path controller **24** sends to control the path switch SG_1 , the most upstream path switch among all the path switches. When the signal S_1 is asserted to turn on the path switch SG_1 , the pulse generator **108** is triggered to output a pulse S_{CONN} with a predetermined pulse width. The pulse S_{CONN} turns on the switch **116** such that the constant current source **118** conducts the control current I_{CTL} from the base of the BJT **110**. The pulse generator **108** determines the pulse width of the pulse S_{CONN} , referred to as a connection period T_{CONN} in this specification because the BJT **110** seemingly connects the capacitor **112** to the node REC when the pulse S_{CONN} appears.

FIG. 5 demonstrates some waveforms of signals in FIG. 4. The sinusoid input voltage V_{AC} in FIG. 5 is negative during the time period between times t_0 and t_{REV} , and becomes positive after time t_{REV} . The time period from time t_0 to time t_{PEAK} is called a charge period T_{CHG} since the rectified input voltage V_{REC} continuously increases, so the capacitor **112** is continuously charged through the diode **114** in FIG. 4. After the time t_{PEAK} when the rectified input voltage V_{REC} starts decreasing, the diode **114** is reversely biased and stops conducting. The discharge switch **110** in the meantime is turned OFF as the control current I_{CTL} is about 0 A, such that the capacitor **112** holds electric energy until the time t_{TGR} , the moment the rectified input voltage V_{REC} drops below the threshold voltage V_{TH2} , the voltage required for driving both the LED groups 20_1 and 20_2 to illuminate. The time period between the times t_{PEAK} and t_{TGR} is referred to as a holding time T_{HLD} because the capacitor **112** constantly stores and holds the electric energy during this time period.

4

At the time t_{TGR} , as the rectified input voltage V_{REC} drops below the threshold voltage V_{TH2} , the signal S_1 is asserted to turn the path switch SG_1 ON, trying to make the current I_{G1} bypass the LED group 20_2 . The asserting of the signal S_1 , nevertheless, triggers the pulse generator **108** in FIG. 4 to provide the pulse S_{CONN} , which as shown in FIG. 5 has a pulse width of a connection period T_{CONN} . During the connection period T_{CONN} , the control current I_{CTL} , as shown in FIG. 5, is a constant more than 0 A. The control current I_{CTL} makes the BJT **110** in FIG. 4 conduct the discharge current I_{DIS} , so the capacitor **112** starts releasing its energy to illuminate the LED string, and the rectified input voltage V_{REC} suddenly raises above the threshold voltage V_{TH3} at time t_{TGR} , as shown in FIG. 5. Shown in FIG. 5 as a comparison to the waveform of the rectified input voltage V_{REC} is a fictitious waveform $V_{REC-OLD}$ demonstrating the original rectified input voltage V_{REC} without the help from the power bank **104**. It is noted that the fictitious waveform $V_{REC-OLD}$, unlike the waveform of the rectified input voltage V_{REC} , continues dropping after the time t_{TGR} . Soon after time t_{TGR} , the signal S_1 is deasserted due to the sudden increase at the rectified input voltage V_{REC} , and that is the reason why the signal S_1 has a very narrow pulse at about the time t_{TGR} in FIG. 5.

After time t_{TGR} , the capacitor **112** continues discharging, and the rectified input voltage V_{REC} ramps down as the electric energy stored in the capacitor **112** is consumed. The discharging ends at time t_{CRS} , when the fictitious waveform $V_{REC-OLD}$, which also represents the absolute value of the sinusoid input voltage V_{AC} , merges with the rectified input voltage V_{REC} . The time period between times t_{TGR} and t_{CRS} is accordingly referred to as a discharge period T_{DIS} . Within the discharge period T_{DIS} , the total number of the illuminating LEDs reduces when the rectified input voltage V_{REC} drops across the threshold voltage V_{TH3} . The duration of the discharge period T_{DIS} depends on the amplitude of the sinusoid input voltage V_{AC} , the capacitance of the capacitor **112**, and the magnitude of the discharge current I_{DIS} . For example, the duration of the discharge period T_{DIS} . The discharge period T_{DIS} is at most equal to the connection period T_{CONN} . The discharge period T_{DIS} is the same as the connection period T_{CONN} in condition that the rectified input voltage V_{REC} is always higher than the absolute value of the AC sinusoidal input voltage V_{AC} during the connection period T_{CONN} .

Another charge period T_{CHG} starts at time t_{CRS} since after that moment the rectified input voltage V_{REC} increases to charge the capacitor **112**.

Some embodiments of the invention have the connection period T_{CONN} less than one third the cycle time of the sinusoid input voltage V_{AC} . For instance, the cycle time of the sinusoid input voltage V_{AC} is $1/60$ sec and the connection period T_{CONN} is less than $1/180$ sec. Preferably, the connection period T_{CONN} is less than one quarter of the cycle time of the sinusoid input voltage V_{AC} .

Unlike FIG. 3, which demonstrates a dark period T_{DARK} when no LED illuminates, FIG. 5 always has at least one LED group illuminating and introduces no dark period T_{DARK} . More particular, when the signal S_1 indicates the absolute value of the sinusoid input voltage V_{AC} is not high enough to drive two LED groups (20_1 and 20_2), the bank controller **106** responsively starts providing to the LED string the electric power stored in the capacitor **112**, so at least one LED group in the LED string could continue illuminating, to avoid the occurrence of the dark period T_{DARK} .

The discharge current I_{DIS} shown in FIG. 5 is a constant in magnitude over the discharge period T_{DIS} , but the invention is not limited to. For example, capable of being a replacement to

5

the integrated circuit **102** of FIG. **4**, the integrated circuit **160** in FIG. **6** according to one embodiment of the invention could cause the discharge current I_{DIS} to increase over time during the discharge period T_{DIS} .

The integrated circuit **160** in FIG. **6** has, among others, a bank controller **166** with a pulse generator **168** and a digital-to-analog converter (ADC) **176**. The pulse generator **168**, as will be detailed soon, provides a pulse S_{CONN} with a pulse width of a connection period T_{CONN} in response to the asserting of the signal S_1 . The pulse generator **168** further provides a digital count result, which is converted by the ADC **176** to generate the control current I_{CTL} , an analog result. As the digital count result increases over time during the connection period T_{CONN} , the control current I_{CTL} increases over time, and so does the discharge current I_{DIS} .

Please refer to both FIGS. **6** and **7**, where FIG. **7** demonstrates some waveforms of signals in FIG. **6**. When the signal S_1 is asserted at time t_{TGR} , the SR flip-flop **170** is set to have logic "1" at its output Q, which also presents the pulse S_{CONN} . When the output Q is "1" in logic, the clock signal S_{CLK} from the clock generator **172** can reach the clock input of the counter **174**, and the clock counter accordingly counts to have its digital count result digitally increased. At time t_{FULL} in FIG. **7** when the digital count result reaches a predetermined number, 1000 for example, the counter **174** resets the SR flip-flop **170** and the Q output of the SR flip-flop **170** becomes "0" in logic to reset the counter **174**, concluding the pulse S_{CONN} . In this example, the pulse S_{CONN} at the output Q of the SR flip-flop **170**, as shown in FIG. **7**, has a pulse width, or the connection period T_{CONN} , about 1000 clock cycles (of the clock signal S_{CLK}). In FIG. **6**, the digital count result of the counter **174** is fed to the ADC **176** to generate the control current I_{CTL} , which ramps upward over time during the connection period T_{CONN} as the digital count result increases. The discharge current I_{DIS} , which the BJT **110** provides by amplifying the control current I_{CTL} , increases over time in the beginning portion of the connection period T_{CONN} , but drops to zero at time t_{CRS} when the waveform $V_{REC-OLD}$ has merged with the rectified input voltage V_{REC} . In the embodiment of FIGS. **6** and **7**, during the connection period T_{CONN} , the discharge current I_{DIS} through the BJT **110** to the node REC is always less than the maximum driving current the current source **25** is designed to drain, as shown by the waveforms of currents I_{G1} , I_{G2} , I_{G3} , and I_{G4} . As derivable from FIG. **7**, a lot of the capacitor voltage V_{CAP} on the capacitor **112**, which is intentionally prepared for driving the LED string, would be consumed by the BJT **25**, and accordingly the active LED count increases over time during the discharge period T_{DIS} since the effective resistance of the BJT reduces as the discharge current I_{DIS} ramps up. This phenomenon is very different from what is shown in FIG. **5**, where the active LED count decreases over time during the discharge period T_{DIS} .

The embodiment shown in FIGS. **6** and **7** is not for limiting the scope of the invention. Since the current source **25** always limits the current through any one of the LED groups **20₁**, **20₂**, **20₃** and **20₄**, the discharge current I_{DIS} through the BJT **110** to the node REC, which is constant or varies, could be equal to or less than the maximum driving current the current source **25** is designed to drain. For example, if the current gain of the BJT **110** is very large, the BJT **110** could perform a short circuit during the discharge period T_{DIS} as the discharge current I_{DIS} is limited by the current source **25**, and the number of the LED groups that emit light decreases as long as the energy stored by the capacitor **112** is continuously consumed, an example result of which is shown in FIG. **5**. In the opposite, if the current gain of the BJT **110** is relatively small, the BJT **110** could replace the role of the current source **25**, and limit the

6

current through any of the LED groups during the discharge period T_{DIS} . In this case, the number of the LED groups emit light could increase if the voltage drop across the BJT **110** is reduced due to the increase of the discharge current I_{DIS} , as exemplified by FIG. **7**.

FIG. **8** demonstrates another power bank **184**, an alternative to the power bank **104** in FIG. **4** or **6**. Instead of using a BJT as a discharge switch, the power bank uses a P-type MOSFET **186**. Moreover, the power bank **184** lacks the diode **114** in FIG. **4**, which provides a charge path for charging the capacitor **112**. During a charge period T_{CHG} , the capacitor **112** could be charged via a parasitic body diode **188** in the P-type MOSFET **186**. During a discharge period T_{DIS} , the control current I_{CTL} could cause a voltage drop across the resistor **192**, and this voltage drop acts as the required gate bias to turn on the P-type MOSFET **186**, such that the capacitor **112** releases its stored energy to the node REC. The resistor **190** connected to the capacitor **112** in FIG. **8** is used to limit the maximum current charging or discharging the capacitor **112**.

While the invention has been described by way of example and in terms of preferred embodiment, it is to be understood that the invention is not limited thereto. To the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

What is claimed is:

1. An LED lamp, comprising:

LED groups arranged in series between a rectified input voltage and a ground voltage;

a path controller configured to control path switches, each path switch for coupling a corresponding LED group to the ground voltage;

a power bank coupled between the rectified input voltage and the ground voltage, comprising:

a capacitor configured to be charged when the rectified input voltage exceeds a capacitor voltage of the capacitor; and

a discharge switch connected between the capacitor and the rectified input voltage; and

a bank controller, configured for determining a connection period and controlling the discharge switch in response to a signal turning ON one of path switches, in order to make the capacitor capable of being discharged to the rectified input voltage during the connection period, the bank controller comprising a pulse generator for generating a pulse with a pulse width of the connection period, the pulse generator comprising:

a counter with a clock input; and

a clock generator for providing a clock signal;

wherein the counter counts based on the clock signal during the connection period, and the connection period ends when a count result of the counter reaches a predetermined number.

2. The LED lamp of claim 1, wherein the bank controller controls the discharge switch to provide a constant discharge current from the capacitor to the rectified input voltage during a discharge period within the connection period.

3. The LED lamp of claim 1, wherein the bank controller controls the discharge switch to provide a discharge current from the capacitor to the rectified input voltage, and the discharge current increases over time during a discharge period within the connection period.

7

4. The LED lamp of claim 1, wherein the bank controller is in response to a signal controlling the most upstream path switch that is for coupling the most upstream LED group to the ground voltage.

5. The LED lamp of claim 1, wherein the discharge switch is a BJT.

6. The LED lamp of claim 5, wherein the bank controller drains a control current from a base of the BJT during the connection period.

7. The LED lamp of claim 6, wherein the control current is a constant or increases over time during the connection period.

8. The LED lamp of claim 1, wherein the discharge switch is a MOSFET.

9. A method for eliminating a dark zone when LED groups arranged in series between a rectified input voltage and a ground voltage generated by rectifying an AC input voltage, the method comprising:

providing path switches, each path switch for coupling a corresponding LED group to the ground voltage;

charging a capacitor when the rectified input voltage exceeds a capacitor voltage of the capacitor;

providing a clock generator to generating a clock signal;

in response to a signal turning ON one of path switches, determining a connection period and starting to count based on the clock signal;

making the capacitor capable of being discharged to the rectified input voltage during the connection period; and ending the connection period when a count result reaches a predetermined number.

10. The method of claim 9, further comprising:

providing a discharge switch connected between the capacitor and the rectified input voltage; and

discharging the capacitor to the rectified input voltage, via the discharge switch, during a discharge period with the connection period.

11. The method of claim 10, further comprising: generating a constant discharge current through the discharge switch during the discharge period.

8

12. The method of claim 10, further comprising:

generating a discharge current through the discharge switch during the discharge period;

wherein the discharge current increases over time.

13. The method of claim 10, wherein the discharge switch is a BJT.

14. The method of claim 13, further comprising:

draining a control current from a base of the BJT during the connection period;

wherein the control current is a constant or increases over time.

15. The method of claim 10, wherein the discharge switch is a MOSFET.

16. A method for eliminating a dark zone when LED groups arranged in series between a rectified input voltage and a ground voltage generated by rectifying an AC input voltage, the method comprising:

providing path switches, each path switch for coupling a corresponding LED group to the ground voltage;

providing a current source connected to the path switches, for limiting a maximum driving current through the LED groups;

charging a capacitor when the rectified input voltage exceeds a capacitor voltage of the capacitor;

in response to a signal turning ON one of path switches, determining a connection period;

providing a discharge switch connected between the capacitor and the rectified input voltage; and

discharging the capacitor to the rectified input voltage, via the discharge switch, during a discharge period with the connection period;

wherein, during the discharge period, a discharge current from the capacitor, through the discharge switch and to the rectified input voltage, is always less than the maximum driving current.

17. The method of claim 16, further comprising: generating a pulse with a pulse width of the connection period.

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